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PRINCIPAL INVESTIGATOR: Miklos Z. Kiss
Doctor Dale E. Sayers

CONTRACTING ORGANIZATION: North Carolina State University
Raleigh, North Carolina 27695

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Miklos Z. Kiss
Doctor Dale E. Sayers

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

North Carolina State University
Raleigh, North Carolina 27695

E-MAIL:
mzkiss@unity.ncsu.edu

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13. ABSTRACT ***(Maximum 200 Words)***
Images of calcifications embedded in breast tissue specimens have been obtained using a synchrotron based diffraction enhanced imaging (DEI) system and subsequently compared to images obtained using synchrotron-based radiography. Of the three specimens imaged, two contained calcifications associated with breast cancer and one was benign. The samples were imaged using 18 keV synchrotron radiation at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory. The DEI images were obtained by placing a Silicon analyzer crystal tuned to the [333] plane in the beam path between the sample and the detector. Contrast of the calcifications is consistently higher in the DEI images when compared to the normal radiographs. This comparison, called the gain value, is the ratio of the peak contrast (or refraction contrast) to the conventional radiographic contrast. In all three specimens the gain values were consistently larger than one, indicating that image contrast using DEI is much higher than from conventional synchrotron-based radiography.

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Introduction

Images of calcifications in breast tissue specimens have been obtained a synchrotron-based DEI system [1, 2] and compared to images obtained using conventional synchrotron-based radiography. Three breast tissue specimens were imaged using 18 keV synchrotron radiation at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory. The DEI images were obtained by placing a silicon analyzer crystal tuned to the [333] plane in the beam path between the sample and the detector. They showed improved contrast of the objects when compared to synchrotron-based radiographs. This comparison, called the DEI gain, is the ratio of the peak contrast (or refraction contrast) to the radiographic contrast. Experiments consistently resulted in gain values larger than one, indicating much higher contrast levels due to DEI. This is part of an ongoing effort to develop a clinical DEI prototype for mammography. One of the challenges in developing the prototype is choosing an optimal digital detector for integration into the system. The recent successes of in showing improved contrast of spiculations and lesions in breast tissue [3] has inspired similar studies to determine the contrast of calcifications. There is a well documented relationship between the presence of calcifications in the breast and breast cancer [4-6].

The samples imaged in this study were breast tissue specimens known to have calcifications. Of these specimens, one was a benign pathological sample. The other two were from mastectomies and contained invasive ductal carcinoma and lobular carcinoma, respectively. More than 100 calcifications in the three samples were analyzed, ranging in estimated sizes from 50 microns to 650 microns. Breast cancer has been connected to the presence of clusters of these small calcifications. It has been hypothesized that early detection can be improved by improving the image contrast of the calcifications.

Annual Summary

Experimental Setup and Methods

Experiments were carried out at the X-15A beamline, a general-purpose beamline at the National Synchrotron Light Source, Brookhaven National Laboratory, Upton, New York. A diagram of the apparatus is shown in figure 1.

The apparatus consisted of a double crystal Bragg monochromator that prepared an imaging beam of 1-mm height and 8-cm width. Images were obtained at 18 keV. The imaging beam was monitored by an ionization chamber to measure the skin entry dose to the various phantoms. Plastic absorbers were used to control the dose to the phantoms. A fast shutter system was used to control the exposure to the detector. The shutter opened when the scanning stage was at a constant velocity and was closed at the end of the scan range before the stage was slowed to a stop. The dose was controlled by a combination of incident beam Lucite absorbers and the scanning speed. For DEI images, an additional silicon [333] analyzer crystal was placed in the beam path between the sample and the detector. The analyzer was tuned by rotating it about its horizontal axis. A second ionization chamber measured the exit dose and the image was recorded using a Fuji HR5 image plate. The plates were read out using a Fuji BAS2500 Image Plate Reader.

Conventional radiographs were obtained by placing the image plate on the sample stage, perpendicular to the beam (as seen in figure 1a), and scanning the sample and plate together through the beam. DEI images were obtained by scanning the sample and the image plate in opposite directions (figure 1b). Raw images were obtained with the analyzer crystal tuned to the

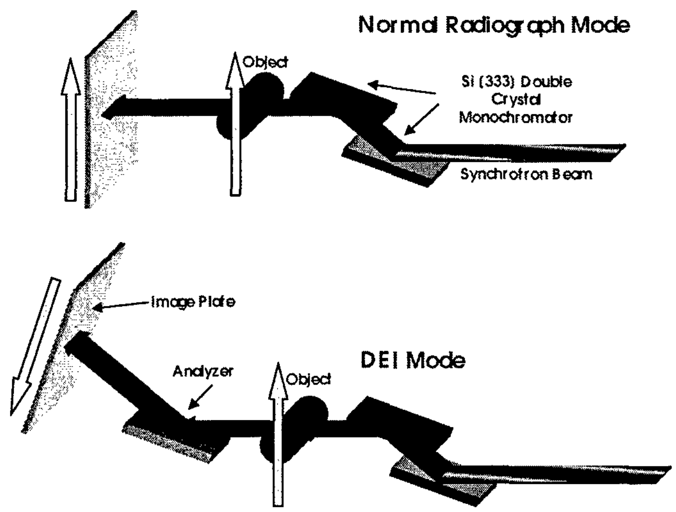

Figure 1. Diagram of apparatus used to acquire images at the X15A beamline at NSLS. Image is not to scale. a) Conventional radiograph mode, b) DEI mode.

Bragg angle (peak images), or on either side of the Bragg peak at angles corresponding the full-width half-maximum (FWHM) value of the rocking curve. The FWHM value for silicon [333] at 18 keV is approximately 3.6 μradians.

In order to characterize the contrast of small calcifications in breast tissue imaged using DEI, three breast tissue specimens were chosen which were known to have calcifications. Table 1 summarizes the tissue samples and the number of calcifications analyzed in each.

Discussion of Results

Figure 2 shows the radiograph (a) peak image (b), refraction image (c) of sample 2. Numbered, red boxes surrounding the calcifications indicate which ones were analyzed. The refraction image is a composite of the images taken at either side of the rocking curve and combined according to the following relation:

$$\Delta\theta_z = \frac{I_H R(\theta_L) - I_L R(\theta_H)}{I_L \left.\frac{\mathrm{d}R}{\mathrm{d}\theta}\right|_{\theta_H} - I_H \left.\frac{\mathrm{d}R}{\mathrm{d}\theta}\right|_{\theta_L}}, \tag{1}$$

where I_H and I_L are the radiation intensities of the images taken on the high-angle and low-angle sides of the rocking curve, respectively. $R(\theta_H)$ and $R(\theta_L)$ are the reflectivities of the rocking curve on the respective sides and $\mathrm{d}R/\mathrm{d}\theta$ are the first derivatives of the rocking curve at the respective angles. The term $\Delta\theta_z$ is applied on a pixel-by-pixel basis. It is clear from the images that the contrast in the peak is much higher than for the radiograph.

Contrast was determined by measuring values for the minimum, maximum and/or background from several vertical line profiles in each image. The radiographic contrast is defined by,

$$C_{rad} = \frac{I_{avg} - I_{\min,rad}}{I_{avg}}, \tag{2}$$

where I_{avg} is the average background in the image, and I_{min} is the minimum value in the object. The peak contrast is given by,

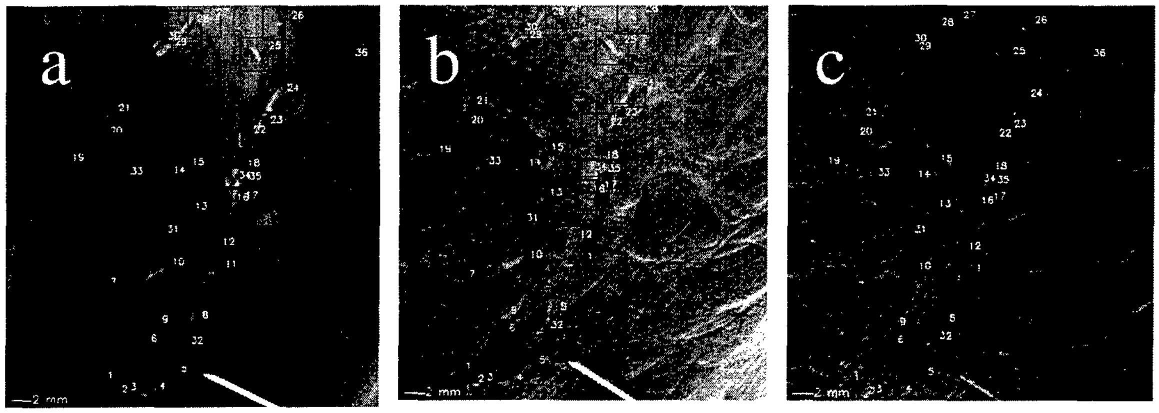

Figure 2. Peak images of the three tissue samples: a) synchrotron-based radiograph, b) peak image, c) refraction image. The numbered, red boxes indicate the calcifications, which were identified and analyzed.

$$C_{peak} = \frac{I_{avg} - I_{\min,peak}}{I_{avg}}, \tag{3}$$

with similar definitions as in equation 2.

In addition to the definition of contrast, signal-to-noise ratios (SNR) have been defined for both the refraction image as well as the radiographic image. The SNR in the refraction image is given by

$$SNR_{ref} = \frac{R_{\max} - R_{\min}}{\sigma_{avg}}, \tag{4}$$

where R_{max} and R_{min} are the maximum and minimum values in the refraction image, and σ_{avg} is the noise level in the background. The noise has been defined as one standard deviation from the mean. Similarly, the SNR for the radiograph is given by,

$$SNR_{rad} = \frac{I_{avg} - I_{\min}}{\sigma_{avg}}, \tag{5}$$

where all the terms are defined above

In comparing the DEI results to the radiographic results, a quantity, called the gain value is defined. For the peak image, the gain is obtained by taking the ratio of the peak contrast to the radiographic contrast:

$$G_{peak} = \frac{C_{peak}}{C_{rad}}, \tag{6}$$

while for the refraction image, the gain is obtained by taking the ratio of the refraction SNR to the radiographic SNR, or,

$$G_{ref} = \frac{SNR_{ref}}{SNR_{rad}}. \tag{7}$$

Figure 3 shows scatter plots of the contrast versus the calcification size for all three samples (samples 1 – 3 shown top to bottom). The comparison in each plot is of the peak contrast with the radiographic contrast. For each sample, regression lines have been fit to the data and the slopes are given. It is clear from the graphs that the peak contrast is consistently higher than the radiographic contrast, regardless of the calcification size. This higher contrast is

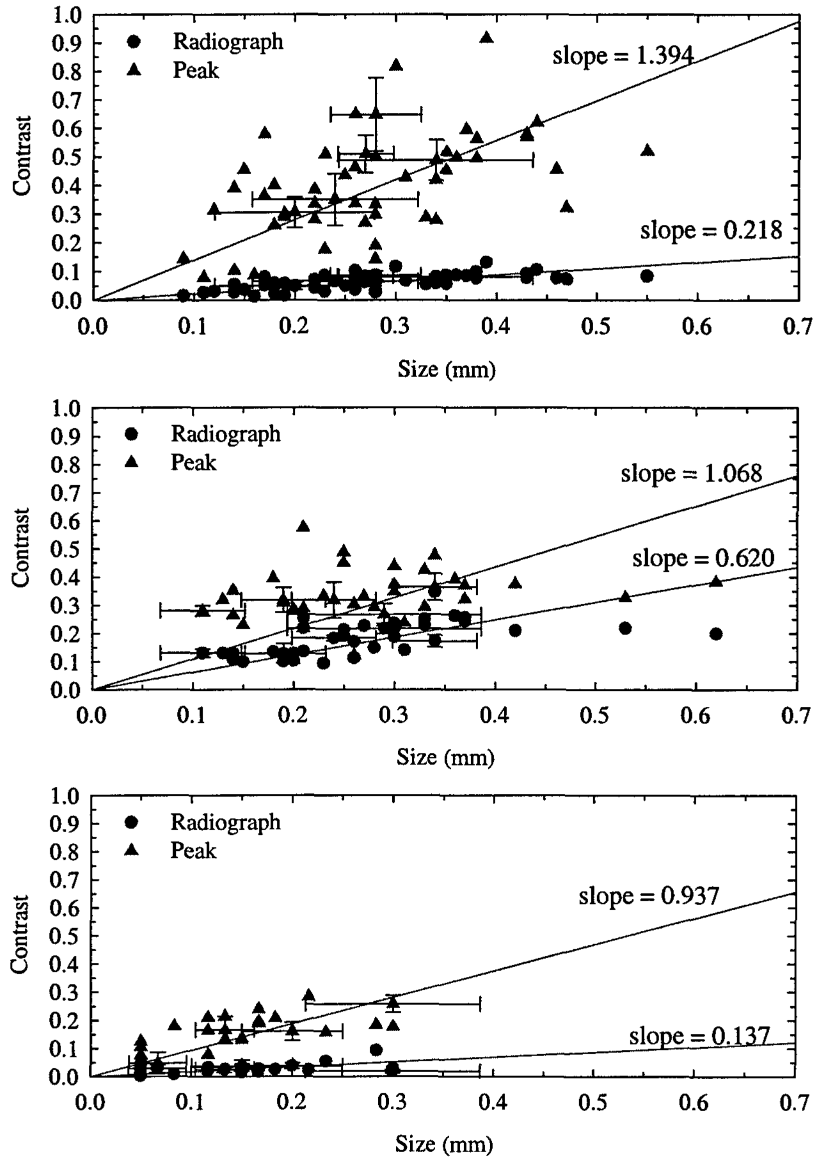

Figure 3. Experimental results. Sample 1 (top), sample 2 (middle), sample 3 (bottom). Slopes are for regression lines fit through the origin.

a direct consequence of the scatter rejection by the analyzer crystal. It is also apparent that the radiographic contrast points tend to lie closer to their regression line than images. This is due in part to the fact that DEI is more sensitive to the uniformity of the calcifications as well as the scatter rejection capability of DEI, which results in the exploitation of additional contrast mechanisms not possible with conventional radiographic techniques. Calcifications tend to be an agglomeration of material of varying homogeneity, which results in varying scatter rejection signatures in DEI. The ratio of the peak slope to the radiograph slope is approximately equal to the average gain value. In general, the gain value is size dependent, but for the specimens studied, this dependence was approximate. Table 1 lists a few of the pertinent results.

Table 1 – Breast Tissue Specimen Results

Sample	Type	No. Calcs	C_{peak} slope	C_{rad} slope	Slope ratio	Avg. G_{peak}
1	Benign	51	1.394	0.218	6.4	6.9 ± 0.4
2	Inv. Carc.	36	1.086	0.620	1.75	1.9 ± 0.1
3	Lob. Carc.	25	0.937	0.173	5.4	7.6 ± 1.8

- **Training Accomplishments**

As a result of the efforts of the past year, a great deal of training value has been gained. Expertise in conducting DEI experiments and proficiency of synchrotron beamline operations have been achieved. These skills have been useful in developing a doctoral dissertation and in training individuals joining the DEI collaboration. The project has also generated new image processing techniques and has resulted in the improvement of existing ones. This is important because DEI is still a relatively new imaging modality. These new techniques will prove invaluable to future researchers as the technique is implemented in the clinic.

Key Research Accomplishments

- Improved and refined the method for quantifying contrast in images obtained using DEI
- Compared DEI contrasts to conventional radiographic contrast and demonstrated the superiority of DEI over conventional radiography with respect to contrast enhancement
- Developed computational techniques for modeling DEI images and for predicting image contrast, especially at near-pixel-sized objects

Reportable Outcomes

- A paper was submitted and accepted for publication (to be published in October 2002): Kiss M.Z., Sayers D.E., Zhong Z., "Comparison of digital detectors for integration into a diffraction-enhanced imaging system," Nucl. Instr. and Meth. A 491 (2002) 165 – 175.
- It is intended that the results of this work will be submitted for publication

Conclusions

This findings in this study clearly demonstrate the ability of DEI to produce higher contrast images when compared with conventional radiographs. This is true even as the object size is approaches the size of a detector pixel (or its PSF). Conventional radiographic contrast suffers in this regime more than enhanced contrast. This becomes important for determining an optimal detector for a clinical DEI device. Further investigations will most likely include chemical composition studies of the calcifications and how this relates to formation and their subsequent imaging. While it is understood that radiographic imaging modalities are currently non-specific for chemical composition of a calcification, it may be possible to determine a relationship between the composition of calcifications and their imaging characteristics.

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DEPARTMENT OF THE ARMY
US ARMY MEDICAL RESEARCH AND MATERIEL COMMAND
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